EFFECT OF PH SOLUTION ON THE WATER ABSORBENCY OF SUPERABSORBENT POLYMER COMPOSITE

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering
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JANUARY 2013

ABSTRACT

Nowadays, superabsorbent polymer composite (SAPC) has been world widely known because of its capacity in contributing beneficial applications in daily life. In this study, Poly Oil Palm Empty Fruit Bunch-co-Acrylamide superabsorbent polymer composite (OPEFB-AM-SAPC) was synthesized by solution polymerization of the Acrylamide (AM) monomer onto OPEFB fibre using Ammonium Persulphate (APS) and N, N-methylene bisacrylamide (MBA) which act as an initiator and crosslinker, respectively. The effects of different pH solution and filler amount towards water absorbency have been identified by studying the optimum condition of each parameter towards water absorbency capacity of polymer. For a parameter of pH solution, the maximum water absorbency was observed at pH 4 for fixed filler amounts. Meanwhile, for the effect of different filler loading, the optimum water absorbency of OPEFB-AM-SAPC was achieved at 2.5 wt% of filler loadings which reveals the well-organized loosely polymeric structure with multiple porous structures that suitable for penetration of water into the polymeric network. These multiple porous structures lead for high water uptake within the network. On the other hand, the characterizations of OPEFB-SAPCs have been carried out by using Fourier Transform Infrared Spectroscopy (FTIR), Thermogravimetric Analysis (TGA) and Field Emission Scanning Electron Microscopy (FESEM). The thermogravimetry analysis result of OPEFB-SAPC at 2.5% filler loading indicate that the SAPC shows a three stage degradation, which unlike the dense unorganized rigid structure been exhibited by the 12.5 wt% filler loading. Meanwhile, FTIR analysis shows OPEFB-SAPC (2.5 wt %) has sharp peak of bonding curves compared to OPEFB-SAPC (12.5 wt%).

ABSTRAK

Pada masa sekarang, penyerap polimer gel (SAPC) telah diketahui secara umum dan meluas kerana kebolehannya yang menyumbangkan banyak kelebihan dalam kehidupan seharian. Di dalam penyelidikan ini, penyerap polimer gel (SAPC) bedasarkan tandan kosong buah kelapa sawit (EFB) disentesiskan menggunakan kaedah pempolimeran cantuman akrilamida (AM) monomer ke atas tulang belakang OPEFB dengan ammonium persulfat (APS) sebagai pemangkin dan N'N'-metilenabisakrilamida (MBA) sebagai pemautsilang dalam membantu proses. Kesan kuantiti pengisi (filler) dan kesan larutan pH yang berbeza terhadap kebolehan daya serap air dipelajari untuk menentukan keadaan kuantiti maksimum kebolehan daya serap air OPEFB-SAPC. Kebolehan daya serap air paling tinggi untuk larutan pH adalah 4 untuk kuantiti pengisi (filler) yang tetap. Selepas itu, daya serap air OPEFB-SAPC paling maksimum adalah 2.5 wt%. Manakala, analisa struktur kimia OPEFB-SAPC dianalisis menggunakan spektroskopi FTIR, TGA dan FESEM.

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LIST OF ABBREVIATIONS

AM	Acrylamide
APS	Ammonium Persulphate
FESEM	Field Emission Scanning Electron Microscopy
FTIR	Fourier Transform Infrared Spectroscopy
HCl	Hydrochloric Acid
MBA	N,N'-methylenebisacrylamide
NaOH	Sodium Hydroxide
N_2	Nitrogen
OPEFB	Oil Palm Empty Fruit Bunch
SAP	Superabsorbent Polymer
SAPC	Superabsorbent Polymer Composite
SPAN	Starch-graft-polyacrylonitrile
TGA	Thermogravimetric Analysis

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Superabsorbent are three-dimensional a cross-linked network of hydrophilic polymers that can absorb large quantities of water, saline or physiological solutions while the absorbed solutions are not removable even under pressure (Hossein et al., 2011). Based on study by Gadallah et al., (2012), to function as an absorbent for aqueous fluids, a polymer must have certain properties which is must be hydrophilic and the polymer must swell in aqueous fluids but must not dissolve. According to Zohuriaan and Kabiri, (2008), the synthesis of the first water-absorbent polymer goes back to 1938 when acrylic acid (AA) and divinylbenzene were thermally polymerized in an aqueous medium. In the late 1950s, the first generation of hydrogels was appeared. These hydrogels were mainly based on hydroxyalkyl methacrylate and related monomers with swelling capacity up to 40-50%. They were used in developing contact lenses which have made a revolution in ophthalmology. The first commercial SAP was produced through alkaline hydrolysis of starch-graft-polyacrylonitrile (SPAN). The hydrolyzed product (HSPAN) was developed in the 1970s at the Northern Regional Research Laboratory of the US Department of Agriculture. Expenses and inherent structural disadvantage (lack of sufficient gel strength) of this product are taken as the major factors of its early market defeat. Commercial production of SAP began in Japan in 1978 for use in feminine napkins.

Because of the superior properties of SAPs, they have found extensive applications such as disposable diapers, feminine napkins, drug delivery systems, and soil for agriculture and horticulture. For the majority of applications, the superabsorbent polymers have to possess high absorption capacity and elevated swelling rate and show a strong swollen gel. Hydrogels with high mechanical strength are required in some applications such as artificial cartilage, controlled drug delivery, hygiene and agricultural uses (Hossein et al., 2011). Recently, based on research from Xie and Wang (2009), the usage of superabsorbent as water managing materials for the renewal of arid and desert environment has attracted great attention as they can reduce water consumption for irrigation, improve fertilizer retention in soil, lower the mortality rate of plants, and increase plant growth rate.

Furthermore, SAPs are used also as scaffolds in tissue engineering where they may have human cells in order to repair tissue. Superabsorbent polymers have the ability to sense environmental changes, like changes of pH and temperature. Hydrophilic networks that are responsive to some molecules, such as glucose or antigens can be used as biosensors as well as in drug systems, disposable sanitary products (for example, diapers, incontinence articles, feminine hygiene products, airlaids and absorbent dressings), and in controlled release drugs. Superabsorbent polymers were also employed in various applications, such as household articles, sealing materials, humectants for agricultural products for soil conditioning, oil-drilling, anti-condensation coatings, water-storing materials in agriculture, absorbent paper products, bandages and surgical pads, pet litter, wound dressings, and as chemical absorbents. Furthermore, they are used in food packaging applications (Jaber, 2012).

In general, there are two types of SAP that available in the market which are synthetic (petrochemical-based) and natural. The graft copolymerization of vinyl monomers on polysaccharides is the example of the natural based SAP where usually been prepared through addition of some synthetic parts onto the natural substrates. The greatest volume of SAP comprises full synthetic or of petrochemical origin which produced from the acrylic monomers, frequently used are acrylic acid (AA) and acrylic amide (AM) (Zohuriaan-Mehr and Kabiri, 2008). This superabsorbent polymer can be prepared by various techniques such as bulk polymerization, suspension-inverse suspension polymerization and polymerization by irradiation. However, the frequently common method used for SAP preparation is solution polymerization technique which is a free-radical initiated polymerization of acrylic acid (AA) and its salts, acrylic amide (AM) with a cross-linker. Before or after the polymerization step, the carboxylic acid groups of the product are partially neutralized. There are few types of initiation often carried out by reaction of a reducing agent with an oxidizing agent (redox system) or chemically with free-radical azo or peroxide thermal dissociative species or. Additionally, radiation is sometimes used for initiating the polymerization. The solution polymerization of AA and AM with a water-soluble cross-linker, e.g., MBA in an aqueous solution is a straight forward process. The reactants are dissolved in water at desired concentrations, mostly about 10-70% and a fast exothermic reaction yields a gel-like elastic product. Then, the product is dried and sieved in order to obtain the required particle size (Zohuriaan-Mehr and Kabiri, 2008). Based on study by Kiatkamjornwong (2007), the major advantage of solution polymerization is the presence of solvent serving as a heat sink. A great variety of hydrogels has been synthesized where the SAP can be made pH-sensitive or temperature-sensitive by using this method as well.

Currently, material's biodegradability has been widely focused on due to the renewed attention towards environmental protection issues. Approximately, 90% of superabsorbent materials are used in disposable articles which most of them are synthetic polymers that are poor in degradability. Poor degradability will eventually leads to the environmental problem. However, according to previous work (Zhang et al., 2007); the degree of degradability of this superabsorbent polymer could be improved by incorporation of biodegradable and renewable natural sources such as starch, cellulose, and chitosan. It was believed that incorporation of biodegradable element is a convenient way to improve biodegradability of corresponding superabsorbent materials. Natural- based SAP polymers have attracted much attention in medical and pharmaceutical fields because of their non-toxicity, biocompatibility and biodegradability (Sadeghi, 2012). Moreover, the introduction of low cost inorganic fillers such as natural filler into a polymer matrix could increase their strength and stiffness properties as well as reduced the production cost (Hossein et al., 2011).

Therefore, this study has been carried out by utilization of natural filler in order to improve the absorbency capacity and their strength. For examples, in Malaysia, agricultural waste materials such as oil palm wastes, paddy straw and rice husk are increasing each year leading to disposal problem and need to manage in a proper way. The conventional method of burning OPEFB for disposal purpose often creates environmental problems in that it generates severe air pollution. Thus, economic utilization of OPEFB in turning its abundant supply from oil palm industry by-products into value-added products will be beneficial. Therefore, grafting of vinyl monomer such as AA or AM onto OPEFB backbone may be used to modify and improve various properties in the original vinyl polymer such as elasticity, absorbency, ion exchange capabilities, thermal resistance and hydrophilicity. The synthesized SAPC has benefited the system by enhancing the swelling ability while reducing the production cost, more environmental friendly and accelerate the generation of new materials for special applications (Hashim and Jamaludin, 2011).

1.2 PROBLEM STATEMENT

Nowadays, development of SAP has been improved from time to time. SAPC made from synthetic polymers possess good characteristics but it is not environmental friendly since it contains toxicity and non-degradability. SAP based on acrylic acid and acrylamide are poor in degradability in application of agriculture and horticulture. As an alternative way, OPEFB used as the filler in SAPC and lower the cost production. Additionally, SAPC that will be produced is biogradable and easy to dispose so it does not pollute the surrounding environment. This SAPC is also able to absorb water higher than synthetic SAPC with proved from recently research that had been going through. Thus, OPEFB based on SAPC may become a new invention to be used in widely agriculture, sanitary goods as well as in horticulture field.

1.3 OBJECTIVE

The main objectives of this research is to study the optimum conditions of oil palm empty fruit bunch (OPEFB) based on the superabsorbent polymer composite by determining:

a) Effect on different of pH solutions towards water absorbency.

b) Effect on amount of filler towards water absorbency.

1.4 SCOPE OF STUDY

The effects of filler amount and effect of different pH solution towards water absorbency have been studied to determine the optimum condition for water absorbency capacity of OPEFB-SAPC. A few parameters required to be controlled in this research which is by fixing pH solutions at pH 2 up to pH 10 while varying amount of filler at range of 5 wt% to 12.5 wt%. In this research, SAPC were synthesized by using solution polymerization with acrylamide (AM) was used as the monomer, ammonium persulphate (APS) was used as the initiator as well as N'N'-methylenebisacrylamide (MBA) as a crooslinker. In sample preparation, three flasks equipped with a stirrer, condenser, thermometer, and nitrogen line were used. The samples were characterized by using FTIR (Fourier Transform Infrared) spectroscopy to indicate functional groups, TGA (Thermal Gravimetric Analysis) to indicate thermal stability of samples and FESEM (Field Emission Scanning Electron Microscope) to examine morphology of superabsorbent polymer composite (SAPC). Finally, the tea-bag method was used to measure the amount of water absorbency.

1.5 SIGNIFICANCE OF STUDY

Superabsorbent polymer composite (SAPC) from oil palm empty fruit bunch (OPEFB) become new materials to be used in the application of agriculture, sanitary goods and horticultural. The significant of this research can reduce overall cost to produce SAPC with the same quality as superabsorbent polymer synthetic since OPEFB is residue where it can be found easily at the palm oil mill around Malaysia. The addition of this research is the SAPC produced has biodegradable element and reducing the environment problems and protect the earth. The swelling ability of this SAP also increases compare to the synthetic SAP which has been proved by the recently research that had been done.

CHAPTER 2

LITERATURE REVIEW

2.1 SUPERABSORBENT POLYMER COMPOSITE (SAP)

According to Zohuriaan-Mehr and Kabiri (2008), superabsorbent polymers are slightly cross-linked hydrophilic polymers with a three-dimensional network structure which are capable of absorbing and retaining large amounts of aqueous fluids even under some pressure. Desired features of superabsorbent polymer (SAP) are high swelling capacity, high swelling rate, and good strength of the swelling gel. SAP hydrogels also known as polymeric materials which exhibit the ability of swelling in water and retaining a significant fraction of water within their structure without dissolving in water or aqueous solution (Brannon-Peppas and Harland, 1990; Buchholz and Graham, 1998). There are two types of SAP which are synthetic (petrochemical-based) and natural. The graft copolymerization of vinyl monomers on polysaccharides are the example of the natural based SAP where usually been prepared through addition of some synthetic parts onto the natural substrate. Absorption capacity of common hydrogels usually not more than 100% (1g/g) but superabsorbent hydrogels can absorb deionized water as high as 1000-100000% (10-1000g/g) which can be seen on Figure 2.1. (Omidian et al., 2004).

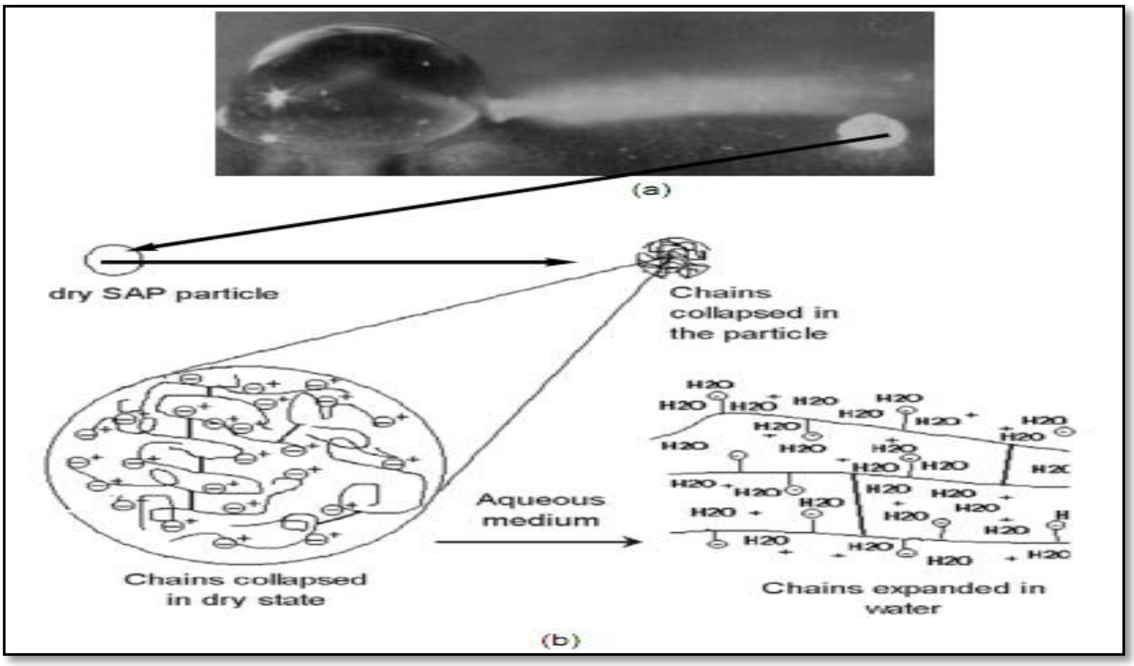


Figure 2.1: Comparison of dry SAP with swollen SAP and schematic of the SAP swelling

Moreover, after water absorption and swelling, SAP particle shape (granule, fibre, film, etc) has to be basically preserved, which the swollen gel strength should be high enough to prevent a loosening, mushy, or slimy state. Traditional absorbent materials such as tissue, papers and polyurethane forms unlike SAP, will lost most of their absorbed water when they are squeezed. Comparisons of water absorptiveness of some common absorbent materials with a typical sample of a commercially available SAP nowadays are shown in the Table 2.1.

Table 2.1: Water absorbency of absorbent materials

Absorbent Material	Water Absorbency (wt %)
Whatman No. 3 filter paper	180
Facial tissue paper	400
Soft polyurethane sponge	1050
Wood pulp fluff	1200
Cotton ball	1890
Superab A-200[a]	20200

2.2 NATURAL BASED SAP

Kiatkamjornwong et al. (2010), used cassava starch for polymer substrate, acrylamide, AM as a grafting monomer, potassium persulfate, KPS as initiator and N,N'-Methylenebisacrylamide (MBA) as crosslinker. The water absorbency of cassava starch-g-polyacrylamide which has been saponified in this experiment was 605 g/g. However, when the testing for the comparison of inorganic filler, the bentonite clay SAP showed the highest water absorption of 730 g/g among the China clay, 650 g/g and silica, 310 g/g. From the study, it shows that the pure SAP without inorganic filler still can produce high water absorbency of 605 g/g but when filler was added it helps in improving the capacity of the water absorbency.

Soy and fish proteins are converted to SAP through modification by ethylenediamine tetraaceticdianhydride (EDTAD). The amino groups of the protein was crosslinked by glutaraldehyde to produce SAP. The dry gel of SAP was capable to absorb 80-300 g of deionized water/g after centrifugating at 214 g. The water absorbency capabality of SAP was depending on the extent modification, protein structure, cross link density, protein concentration and environmental conditions like pH, ionic strength and temperature (Hwang and Damodran, 1996). This research show that the protein after modification could be used as polymer substrate and produce SAP with high water absorption.

Starch phosphate-graft-acrylamide or attapulgite superabsorbent composite was prepared by graft-copolymerization among starch phosphate, acrylamide, and attapulgite in aqueous solution (Raju et al., 2005). The factors influencing water absorbency of the superabsorbent composite such as the molar ratio of NaOH to AM and the amount of starch phosphate and attapulgite were studied. Hence, the superabsorbent composite achieved the highest equilibrium water absorbency of 1268 g/g when the molar ratio of COO^-, COOH, and $CONH_2$ is 10:3:11, the weight ratio of AM to starch phosphate is 5:1, and 10 wt% attapulgite was incorporated. In this research, the results show that the phosphorylation of starch and the introduction of attapulgite could greatly improve equilibrium water absorbency superabsorbent composite.

The effects of vermiculite content on water absorbency were studied by Zheng et al. (2007), in a series of superabsorbent composites that were synthesized by copolymerization reaction. This copolymerization reaction was occurred between a partially neutralized acrylic acid on unexpanded vermiculite (UVMT) micropowder using N,N′-methylenebisacrylamide (MBA) as a crosslinker and ammonium persulfate (APS) as an initiator in aqueous solution. They found that the equilibrium water absorbency increased with increasing UVMT content and the concentration of 20 wt % clay gave the best absorption of 1232 g/g in distilled water and 89 g/g in 0.9 wt % NaCl. From the result obtained in this research, it is found that the UVMT helps in improving the absorbency of water and also saline solution.

2.3 OIL PALM EMPTY FRUIT BUNCH (OPEFB)

According to Shinoj et al. (2011), the lignocellulosic materials are from the excess of oil palm tree which can be extracted from oil palm fronds, trunks and also empty fruit bunch. OPEFB is the fibrous mass left after separating the fruits from fresh fruit bunches where it has 73% fibers among the various source in oil palm tree. However, these waste materials will cause tremendous environmental problems when left in field. Furthermore, the additional advantage of natural fiber than glass fiber is that it can be composted at the end of their life cycle.

Figure 2.2: Oil Palm Empty Fruit Bunch Fibrous

From the research of Jawaid et al. (2010) about the hybrid composites made from OPEFB/jute fibres, they found that the hydrophilic properties of lignocellulosic materials and capillary action will cause the intake of water when the samples were soaked into water. It is also observed that the thickness swelling for the pure OPEFB composite with the value of 9.12 % was the highest water absorption among different types of composite. The next highest water absorption among the different type composite is pure OPEFB with the value of 21.39 % which resulted from the high porosity on the surface of pure OPEFB composite.

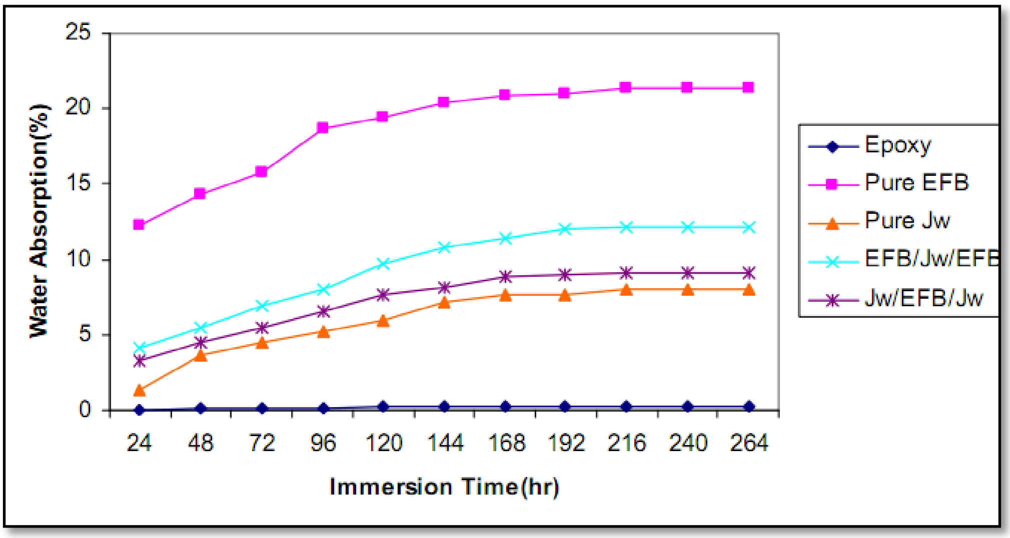


Figure 2.3: Water absorption (%) of OPEFB reinforced hybrid composites

Moreover, according to Jawaid et al. (2010), the water absorption behaviour of the polymer composite depends on the ability of the fibre to absorb water due to the presence of hydroxyl groups. From their study, it shows that the pure OPEFB has higher potential than pure jute mate and hybrid composite (OPEFB/jute mate) in water absorption, which by this reason strengthens the usage of OPEFB as filler in this research.

2.4 TECHNIQUE OF POLYMERIZATIO N

The polymerization techniques often used in preparing superabsorbent polymer (SAP) either by solution or suspension polymerization. Each of the techniques has its own advantages and disadvantage depends on the product been produced. The mechanism in preparation of SAP was shown in Figure 2.5.

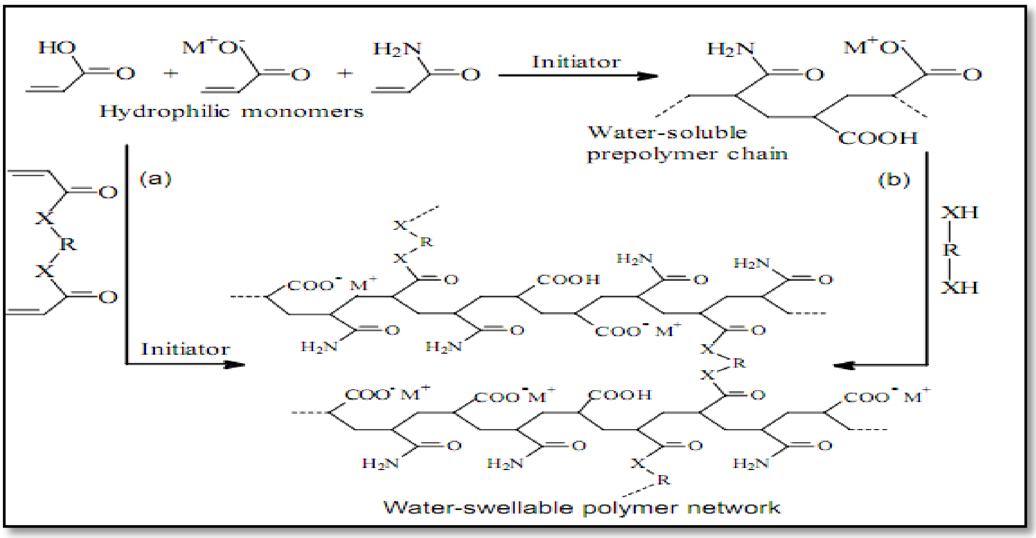


Figure 2.5: The mechanism in preparation of SAP

According to Zohurian-Mehr and Kourosh (2008), the solution technique frequently used for SAP preparation is a free radical initiated polymerization of acrylic acid (AA) and its salts, acrylic amide (AM) with a cross-linker. Before or after the polymerization step, the carboxylic acid groups of the product are partially neutralized. There are few types of initiation often carried out by reaction of reducing agent with an oxidizing agent (redox system), or chemically with free radical azo or peroxide thermal dissociation species. The process of AA and AM with a water soluble cross-linker, e.g., N’N’-methylenebisacrylamide (MBA) in an aqueous is a straight forward process. The reactants at desired concentration about 10-70 % are dissolved in water and a fast exothermic reaction yields a gel-like elastic product. Then, the product is dried and sieved to obtain the required size particles. Based on study by Kiatkamjornwong (2007), stated that the major advantage of the solution polymerization is the presence of solvent serving as a heat sink. A great variety of hydrogels has been synthesized where the SAP can be made pH-sensitive or temperature-sensitive by using solution polymerization method.

From the research of Zohurian-Mehr and Kourosh (2008), the suspension polymerization is also referred as inverse suspension because the process is water-in-oil (W/O) has been chosen. The monomers and initiator are dispersed in the hydrocarbon phase as a homogenous mixture. Each particle contains all the reactive species when the initiator dissolves in the aqueous phase and behaves like an isolated micro-batch polymerization reactor. According to Kiatkamjornwong (2007), the mixture is thermodically unstable and being stabilized by addition of stabilizer. Besides, the SAP with high swelling ability and fast absorption kinetics is the production of inverse suspension where it is a highly flexible and versatile technique. The products from the continuous organic phase are easily removed by filtration or centrifugation. Furthermore, it is an advantageous method because the products obtained as powder or microspheres (beads) and grinding is not required.

However, the solution method may often preferred by manufacturers for a general production of SAP with acceptable swelling properties, the less expensive and faster techniques rather than suspension techniques.

2.5 GENERAL REACTION AND MECHANISM OF SAPC

The superabsorbent composite, was prepared by graft copolymerization of acrylic acid onto carrageenan in the presence of a crosslinking crosslinking agent and powdery kaolin. Ammonium persulfate was used as an initiator. The persulfate is decomposed under heating and produced sulfate radicals that abstract hydrogen from one of the functional groups in side chains of carrageenan backbones. So, this persulfate-saccharide redox system results in active centres capable to radically initiate polymerization of acrylic acid led to a graft copolymer. Since a crosslinking agent, e.g. MBA, is presented in the system, the copolymer comprises a crosslinked structure (Sadeghi et al., 2012).

In addition, other cross-linking agent were also used including 1, 4-butanediol diglycidyl ether (1, 4-BDGE), and ethylene glycol diacrylate (EGDA). Ethylene glycol diacrylate was chosen because it is a well-known cross-linking agent that is reported in the literature as a cross-linking agent for superabsorbent polymers. 1, 4-Butanediol diglycidyl ether was used for the first time as cross-linking agent for superabsorbent polymer.

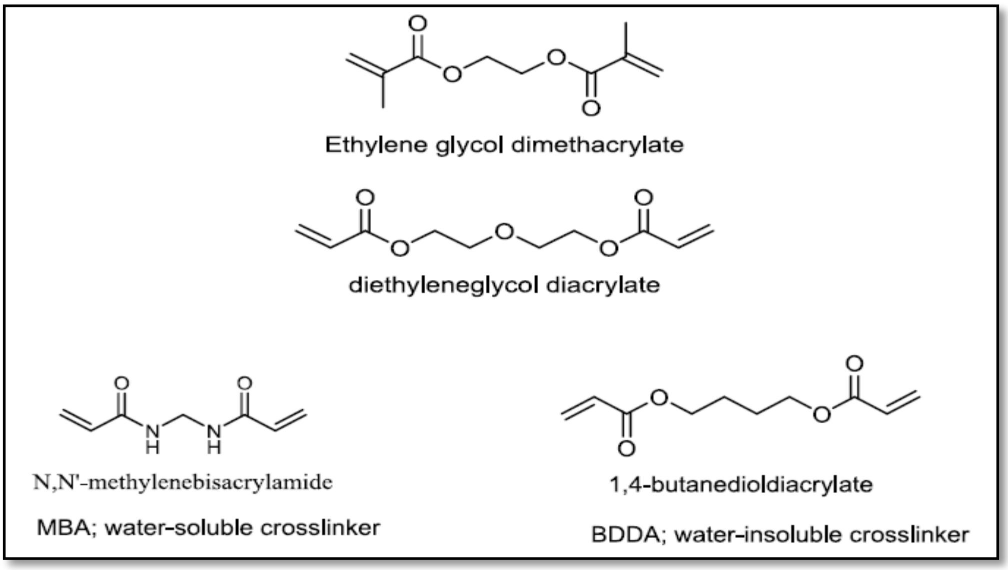


Figure 2.6: Structures of some of the cross-linking agents

There are three principal bonding types that are used to bind the polymer chains together: covalent, ionic, and hydrogen bonds. Two basic methods are used to introduce covalent crosslinks. First, covalent crosslinks are formed when the major monomers (e.g., acrylic acid) is copolymerized with a di-,tri-, or tetra – vinyl monomer for instance N,N-methylenebis(acrylamide), 1,1,1-trimethylolpropanetriacrylate, or as well as tetraallyloxyethane, in a free radical initiated addition polymerization.

Covalent cross-links are also introduced by reacting the polymer chains with a di- or tri - functional reagents that reacts with the carboxylic acid groups by means of a condensation or addition reaction. Second, ionic cross-links are formed by reacting a polyvalent ion of opposite charge with the charged polymer chains. The crosslink forms as a result of charge association of the unlike charges. Because the bond is formed by ion association (charge neutralization) the chemical structure of the cross-linker is less important in determining the placement of the cross-links compared with covalent cross-links. If ionic components are present in the liquid to be absorbed, ion exchange may occur with the ionic cross-links, which may alter the nature of the crosslinks and the behaviour of the polymer in ways that may be unforeseen. Also because the interionic reaction is very fast. The incorporation of the crosslink and the resulting structure of the crosslinked polymer can be difficult to control.

The third type of crosslink is the physical crosslink, which is usually formed by means of hydrogen bonding of segments of one chain with the segments of another chain is shown (Jaber, 2012).

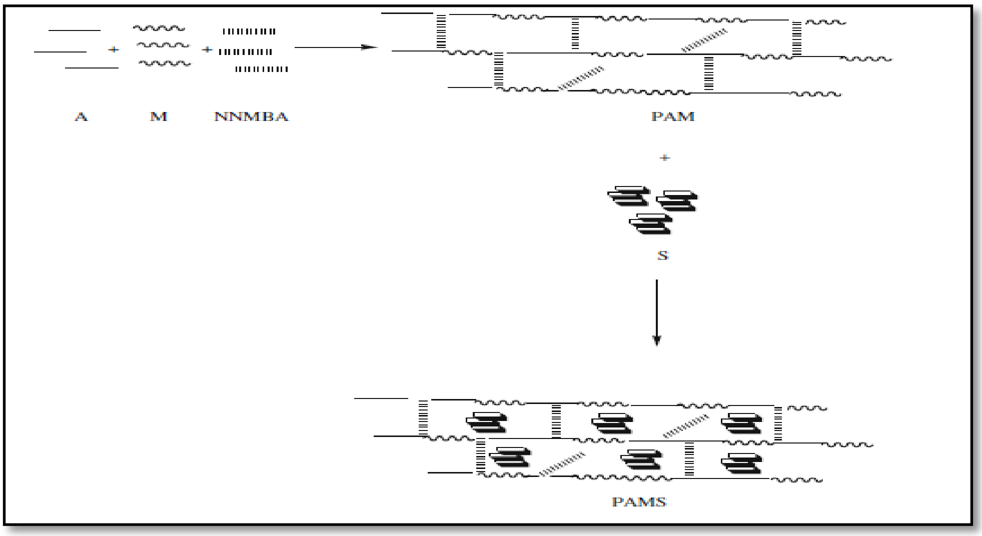


Figure 2.7: Preparation of poly(acrylamide/maleic acid) hydrogel (PAM), and Poly (acrylamide/maleic acid)-sepiolite composite hydrogel (PAMS). (A Acrylamide, M maleic acid, NNMBA N,N0- methylenebisacryl amide, S sepiolite)

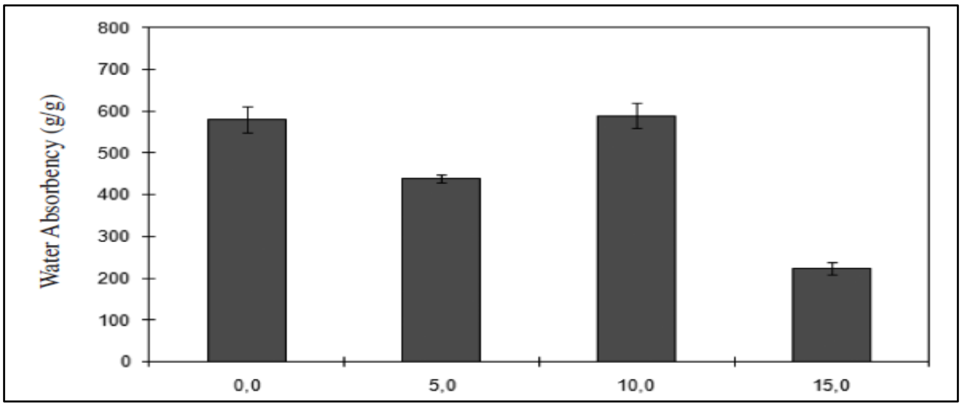
Source: (Oztop et al., 2009)

Poly(acrylamide/maleic acid)–sepiolite composite hydrogels were prepared by free radical crosslinking and copolymerization of acrylamide, sepiolite and maleic acid with a small amount crosslinker (NNMBA) in aqueous solution. APS and TEMED were used as the initiator and the accelerator, respectively. At polymerization, the possible step is a reaction amongst AAm and anionic comonomer, M and crosslinker molecules by the process of the unpaired electron transfer to the monomeric units, so that they in turn become reactive. Another monomer or comonomers can be attached and activated in the same way resulting in a three dimensional network. Sepiolite molecules can be incorporated into chains simultaneously (Oztop et al., 2009).

2.6 EFFECT OF FILLER (OPEFB) AMOUNT

The influences of oil palm empty fruit bunch towards water absorbency give a strong effect in synthesizing the superabsorbent polymer composites. According to Shafinaz and Shahrir (2011), small amount of filler (5 wt% of OPEFB) does not provide enough crosslinking point within the SAPC polymeric network space, thus decreased the water absorption capacity. However, the increasing of OPEFB filler contents (10 wt% of OPEFB) enhance the ability of water absorbency due to the OH molecules on the OPEFB backbone could react with AAm monomer, which benefit the system by forming a network structure.

Moreover, as further increase in OPEFB amount from 10 wt% to 15 wt% reduce the ability of water absorbency due to the decreasing in elasticity of SAPC. This may be attributed to the fact that additional OPEFB fibre in the SAPC system results in the generation of more crosslink points in the polymeric network. This is because it contains a lot of hydroxyl groups to form superfluous network point, hence increases the network density of the composite which it leads to a more difficult permeation of water into the SAPC system.



Amount of OPEFB (wt %)

Figure 2.8: The effect of filler amount towards water absorbency